The PreCam Survey: A Proposal to the University of Michigan Department of Astronomy for Observing Time on the Curtis-Schmidt Telescope in late-2010 and early-2011

PI: John Peoples (FNAL; peop@fnal.gov)

CoI: Sahar S. Allam (FNAL)

CoI: James T. Annis (FNAL)

CoI: David Burke (SLAC)

CoI: Luiz da Costa (Observatório Nacional, Brazil)

CoI: Darren DePoy (Texas A&M)

CoI: David Gerdes (University of Michigan, Dept. of Physics)

CoI: Rich Kron (FNAL/University of Chicago)

CoI: Kyler Kuehn (Argonne National Lab)

CoI: Steve Kuhlmann (Argonne National Lab)

CoI: J. Allyn Smith (Austin Peay State University)

CoI: Douglas L. Tucker (FNAL)

CoI: Others…

Abstract

The Dark Energy Survey (DES) is an upcoming 5000 sq deg *grizy* imaging survey of the Southern Galactic Cap that will be conducted on the CTIO Blanco 4m telescope with a new wide-field mosaic camera (the Dark Energy Camera, or DECam).

The proposed PreCam Survey is a quick, bright survey within the DES footprint in the DES *grizy* filter system using a small mosaic camera of DECam CCDs placed on the University of Michigan Department of Astronomy's Curtis-Schmidt telescope at CTIO. A major goal of the PreCam Survey is to provide improved photometric calibrations for the DES using what is, in essence, a $1/32^{nd}$-scale version of the Dark Energy Camera.

The default PreCam Survey strategy is to cover the full DES footprint in 1.5 passes (one pass with 50% overlaps) in each of the 5 DES filters. This would require approximately 100 scheduled nights on the Curtis-Schmidt. An alternative strategy is also being considered, in which the PreCam Survey would cover only 10% of the DES footprint in a sparse grid in RA and DEC, but that each field in this grid would be observed 10 times in each of the 5 DES filters; this alternative strategy would, like the default strategy, require 100 scheduled nights on the Curtis-Schmidt. Of the 100 scheduled nights we are requesting, 70 would be for PreCam Survey operations, 7 nights (10% of 70 nights) would be for Chilean time, and 23 would be for commissioning of the PreCam hardware. We are requesting a block of time in August/September 2010, and a second block of time in November 2010 – January 2011.

Its large field-of-view makes the Curtis-Schmidt telescope the only viable option among the small telescopes at CTIO for completing such a survey in a reasonable amount of time. On the Curtis-Schmidt, the PreCam instrument's field-of-view is 1.6° x 1.6° (or 2.56 sq deg); on the SMARTS Yale 1m, the PreCam's field-of-view is only 0.34° x 0.34° (or 0.12 sq deg).

Scientific Justification

The Dark Energy Survey (DES) is an upcoming 5000 sq deg *grizy* imaging survey of the Southern Galactic Cap down to ~24th mag (10σ, galaxies) in order to probe the nature of the Dark Energy by constraining its equation of state parameter *w* and its energy density using four different approaches:

1. the clustering of mass (via weak lensing) as a function of (photometric) redshift,
2. the clustering of galaxies as a function of (photometric) redshift,
3. the number of galaxy clusters as a function of (photometric) redshift, and
4. the magnitude at peak brightness of Type Ia supernovae as a function of (photometric and spectroscopic) redshift.

The DES will be conducted over 525 nights in the 2011-2016 time frame on the Blanco 4m telescope at CTIO, and it will employ a new wide-field (3 sq deg) imaging camera, called the Dark Energy Camera (or "DECam") for this purpose.

The DES has stringent photometric calibration requirements, with an all-sky relative photometry requirement of 2% (0.02mag) and a goal of 1% (0.01mag) rms. In other words, the DES photometry is required to be internally consistent to 2% rms (goal: 1% rms) over the full survey area. This is a requirement that took the Sloan Digital Sky Survey (SDSS) several years to achieve (and the goal of 1% photometry was only reached by SDSS in the final year of SDSS-II). Although, due to its strategy of multiple layers of the survey footprint in each filter over the course of 5 years, the DES can in principle self-calibrate, additional data can help the DES achieve its calibration goals sooner (say, within the first year or two rather than after the full 5 years), produce many useful cross-checks, and provide substantial contingency in the photometric calibrations error budget.

The proposed PreCam Survey is a quick, bright survey within the DES footprint in the DES *grizy* filter system using a small mosaic camera of DECam CCDs placed on the University of Michigan Department of Astronomy's Curtis-Schmidt telescope at CTIO. The goal of the PreCam Survey is to calibrate many bright stars (hundreds per square degree fainter than the DES saturation limit) across the DES footprint in the DES *grizy* filter system that can be used for DES calibrations. Benefits that the PreCam Survey would provide to the DES photometric calibrations include:

1. extinction standards throughout the DES footprint, permitting better nightly photometric solutions during DES operations;
2. an additional layer of observations across the DES footprint, allowing for improved global relative calibrations, helping DES achieve its requirement of 2% global relative calibrations sooner and helping DES achieve its long-term goal of 1% global relative calibrations;
3. good transformations relations between the SDSS and DES photometric systems via PreCam observations along the SDSS equatorial Stripe 82; and
4. *y*-band standard stars (for which there is currently a great lack).

Furthermore, the PreCam Survey would provide these additional benefits to DES:

1. a stellar catalog for DECam image quality monitoring during the first year or two of DES operations;
2. intensive, real on-sky tests of a DECam CCD mosaic camera ahead of DECam commissioning;
3. science data in the DES filters for bright objects (e.g., red giant stars in Milky Way star clusters or supernovae in nearby galaxies within the PreCam footprint) that would otherwise saturate (and thus be unusable) in the standard DES science exposures.

Experimental Design

PreCam Instrument

The PreCam instrument will consist of a 2 x 2 array of 2048 x 2048 LBNL CCDs. These are the same CCD's from which the guide and focus CCD's for DECam will be selected, which are in turn identical to the "science" CCD's in DECam except for the format. The science CCDs have a 2048 x 4096 pixel format. PreCam could also use 2 of the 2048 x 4096 science CCDs. Both types of DECam CCD have 15-micron pixels. The choice between the two formats will be made on the basis of the availability of these devices once production and testing of all devices has been completed. The front-end electronics and data-acquisition system are the same as for DECam and are the preproduction prototypes. The design of the DECam vacuum-interface board is being modified to adapt to the special needs of the smaller PreCam dewar, and the subsequent fabrication is straightforward. A set of 4-in square DES *grizy* filters has been ordered, and these filters will be used for the PreCam Survey.

Curtis-Schmidt Telescope

There are several small telescopes on the Tololo plateau that could conceivably be used for the PreCam Survey, but the need to cover a large fraction of the 5000 sq deg DES footprint in a relatively short period of time (see next section) drives us to the Curtis-Schmidt. On the Curtis-Schmidt, the PreCam instrument, with a pixel scale of 1.43 arcsec/pixel, has a field-of-view is 1.6º x 1.6º (or 2.56 sq deg); on the SMARTS Yale 1m, the PreCam instrument has 0.3-arcsec pixels and a field-of-view of only 0.34º x 0.34º (or 0.12 sq deg). Even considering that the SMARTS 1m's larger effective aperture would reduce exposure times, the roughly factor of 20 greater area in the field-of-view of the PreCam on the Curtis-Schmidt greatly reduces the time for survey completion. Furthermore, our previous experience with the Curtis-Schmidt and the Tek2k#5 CCD indicates that this telescope can achieve good stellar photometry even with large pixel scales (see Figure 3). To make the most of the Curtis-Schmidt's field-of-view, the DES will provide a new folding flat for the Curtis-Schmidt (to reduce vignetting). The DES will also provide a new flat-field screen + illumination system for the Curtis-Schmidt.

PreCam Survey Strategy

We are looking at two alternative strategies for the PreCam Survey: the Full Footprint Plan and the Rib & Keel Plan. We are currently preparing simulations to determine which of these two alternatives provides the better photometric calibrations for the DES.

Full Footprint Plan

The goal of the Full Footprint Plan is to observe the entire 5000 sq deg of the DES footprint in single pass, with large overlaps, in *grizy* down to 1.5 mag fainter than the point-source saturation limit of a nominal 100-sec DES science exposure.

Details of the PreCam Survey exposure time calculations can be found in Table 1. Consider, for instance, the PreCam exposure time calculation for *r*-band. The expected saturation limit for point-source photometry in a nominal 100-sec DES science exposure is $r \approx 16.3$ (Column 4 of Table 1). To permit a sufficiently large magnitude overlap with the unsaturated bright end of the DES point-source photometry, the PreCam Survey point-source photometry should extend 1.5 mag deeper, or to $r \approx 17.8$ at S/N=50 (Column 5). The PreCam magnitude limit for a S/N=50 point source drives the PreCam Survey exposure time (for *r*-band, this is 51 sec; Column 2), which in turn determines the PreCam Survey's point-source saturation limit ($r \approx 13.2$; Column 3) and point-source S/N=5 detection limit ($r \approx 20.7$; Column 6). Table 1 also tabulates the estimated number of useable PreCam Survey stars per square degree at the South Galactic Pole ($b^{II} = -90°$), where "useable" refers to stars with magnitudes between the nominal DES saturation limit and 1.5 mag fainter; e.g., for *r*-band, it is estimated that there are 265 stars per square degree at the Galactic Pole between r=16.3 and r=17.8. Note that, since these estimates are for the Galactic Pole, they represent lower limits to the actual number of stars per square degree expected in a typical PreCam exposure.

Table 1: Exposure Calculations for Point Sources in the Baseline PreCam Survey

Band (1)	PreCam Exposure Time [seconds] (2)	PreCam saturation limit (3)	DES saturation limit (100s exposure) (4)	PreCam mag limit (S/N=50) (5)	PreCam detection limit (S/N=5) (6)	# Stars per sq deg, DES sat to PreCam S/N=50 (7)
g	36	12.8	16.3	17.8	20.9	186
r	51	13.2	16.3	17.8	20.7	265
i	65	13.4	16.2	17.7	20.5	344
z	162	14.1	16.0	17.5	20.1	317
y	73	11.6	14.3	15.8	18.5	150

To summarize our *r*-band exposure time example, we want PreCam to measure stars brighter than r=17.8 with a S/N ≥ 50. To do this, we need a PreCam exposure time of 51 seconds in *r*. Such an exposure time will typically provide at least 265 stars per square degree between the saturation (brightness) limit of a nominal DES science exposure (r=16.3) and the S/N=50 magnitude (faintness) limit of a PreCam r-band exposure (r=17.8).

To estimate the total time to completion for the Full Footprint Plan, we will assume a baseline mosaic camera that is composed of 4 DECam 2k x 2k CCDs, which have a readout time of 10 sec. The total exposure time for all five filters is 387 sec; including readout time expands this number to a total of 437 sec (7.28 min) per pointing. Survey efficiency dictates that we avoid large slews; for the PreCam, most slews should be less than 5 deg. Pat Seitzer has measured the slew time of the Curtis-Schmidt to be 17 sec for a 5 deg slew; for our estimate, we conservatively assume an average slew time of 30 sec. This brings our total to 467 sec per pointing. As previously noted, PreCam when mounted on the Curtis-Schmidt will provide a field-of-view of 2.56 sq deg; thus it would require 1953 pointings to cover the 5000 sq deg of the DES footprint. However, if a filled PreCam footprint is to achieve good global relative calibrations (as for DES, but with a single pass), then a substantial overlap between fields is necessary. Assuming the overlap increases the number of pointings by 50%, the total number of exposures (single pass) is at least 2930. At 1 pointing per 467 sec and at 7 hours per night, the survey footprint could be covered in 54 full nights. The actual number of nights needed to be scheduled will be larger, accounting for non-optimal RA accessibility for given observing runs, calibration exposures for PreCam itself, bright-time avoidance for *g* and *r* exposures, the fact that not all exposures are science-quality, etc. These inefficiencies amount to about a factor of 1.25. Finally, not all of the scheduled nights will be photometric, which requires an additional factor of 1.3 (see Figure 1, which shows that December and January are photometric 78% of the time, based on CTIO 30-year records). To cover the footprint once will therefore realistically require at least 88 scheduled nights.

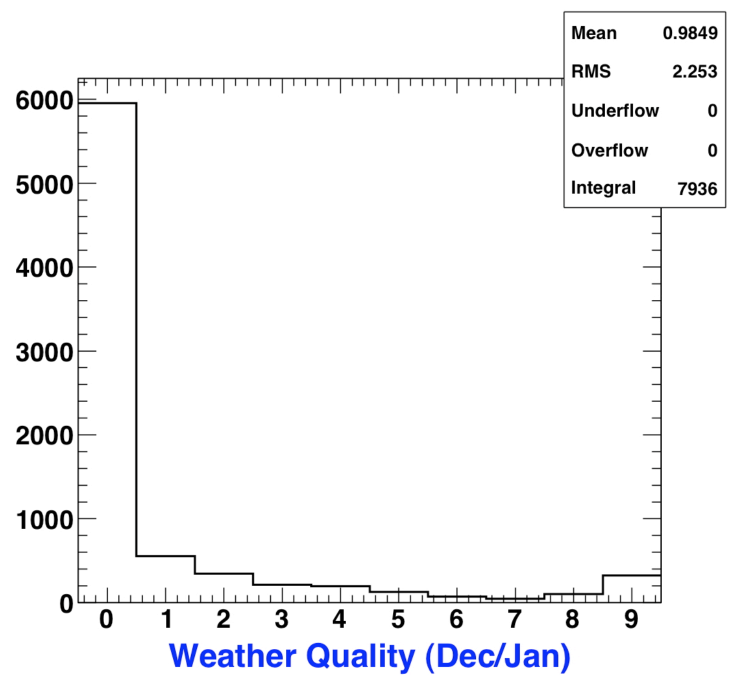

Figure 1: A plot of the sky conditions (0=clear->8=overcast; 9=unknown) for the months of December and January from CTIO's 30-year archive. According to this chart, the observer-estimated sky conditions are ~78% photometric in December and January. (Credit: S. Kuhlmann)

We understand that there may be up to 100 nights available on the Curtis-Schmidt in late-2010/early-2011. We therefore propose, if we follow the Full Footprint plan, to schedule 23 nights for commissioning, 70 nights for PreCam Survey operations, and 7 nights for Chilean time (10% of 70), for a total of 100 nights. The 70 nights of operations mean that we will likely only achieve 80% (70/88) coverage of the DES footprint. Although 100% coverage is preferred, 80% coverage should satisfy most of our calibration goals.

The Rib and Keel Plan

The Rib and Keel Plan is an alternative proposal for the PreCam Survey strategy that is currently under discussion. It gets it inspiration from the SDSS Apache Wheel observations, which form the basis of the recent "über-calibratration" of the SDSS (N. Padmanabhan et al. 2008, *ApJ*, 674, 1217). In the Rib and Keel Plan, the goal is to achieve 1% relative photometry in the manner of the SDSS Stripe 82 over a sparse grid within the DES footprint. An example grid is shown in Figure 2; the term "Rib and Keel" refers to the fact that the grid pattern is reminiscent of the support structure of a ship's hull. The idea is to observe a 500 sq deg cross-hatch (10% of the DES footprint) multiple times to yield a very robust grid with sub-percent calibrations. The baseline plan is to observe each grid line ~10 times, with the intersection points observed ~20 times each. The DES photometry would then be tied to this extremely well calibrated framework. This plan assumes the same exposure times (36 sec in *g*, 51 sec in *r*, 65 sec in *i*, 162 sec in *z*, and 73 sec in *y*) and the same number of pointings (2930) as the Full Footprint Plan described above, and thus it requires the same number of scheduled nights (88).

That said, the Rib & Keel Plan is much more robust to a reduction in the effective number of scheduled nights of PreCam Survey operations. Reducing the number of scheduled nights of operations from 88 to 70 could easily be dealt with by reducing the number of repeat observations from 10x to 8x at a relatively small marginal increase in the errors in the resulting star catalog (assuming the errors go as root-N). Thus, as with the Full Footprint Plan, we can request 100 nights, of which 23 nights would be for commissioning, 70 would be for PreCam Survey operations, and 7 would be for Chilean time (10% of 70 nights).

More details of the Rib and Keel Plan can be found at this URL:
`http://des-docdb.fnal.gov/cgi-bin/ShowDocument?docid=3404` .

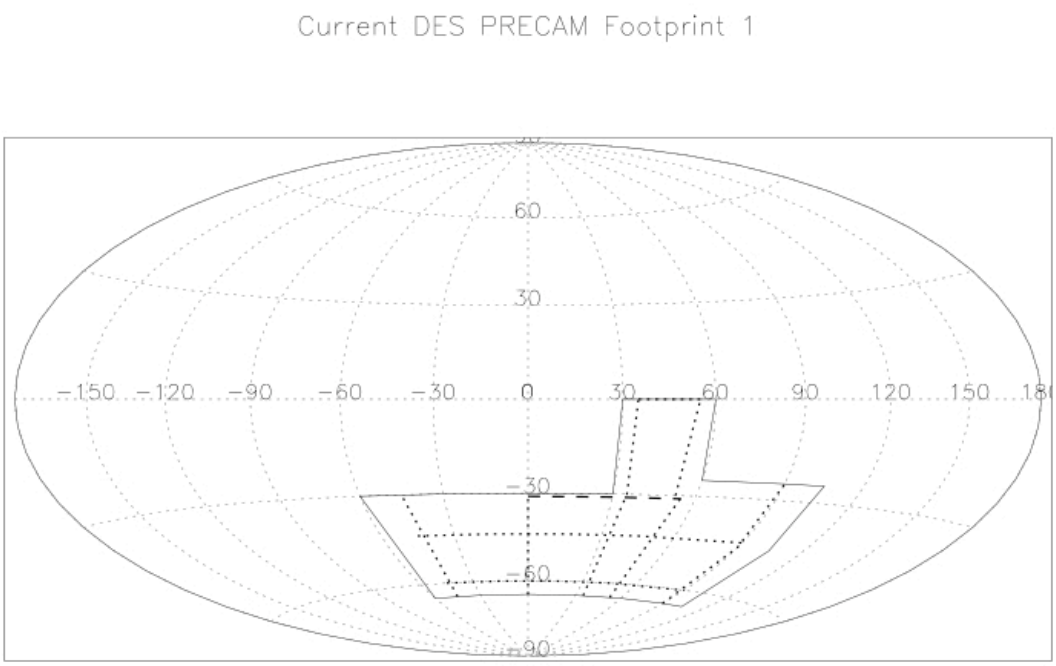

Figure 2: One option for the Rib and Keel Plan. The solid lines demark the DES footprint. The dotted and dashed lines are one option for the grids that the PreCam would observe under this strategy. (Credit: Melissa Butner)

Observing Run Details

Run 1:

We request 23 nights in August/September 2010 to commission the PreCam hardware. We will use our own camera (the PreCam) and filters (a set of 4-in DES *grizy* filters).

Run 2:

We request 77 nights in November 2010-January 2011 for PreCam operations (70 nights) and for Chilean time (7 nights = 10% of 70 nights). We will use our own camera (the PreCam) and filters (a set of 4-in DES *grizy* filters).

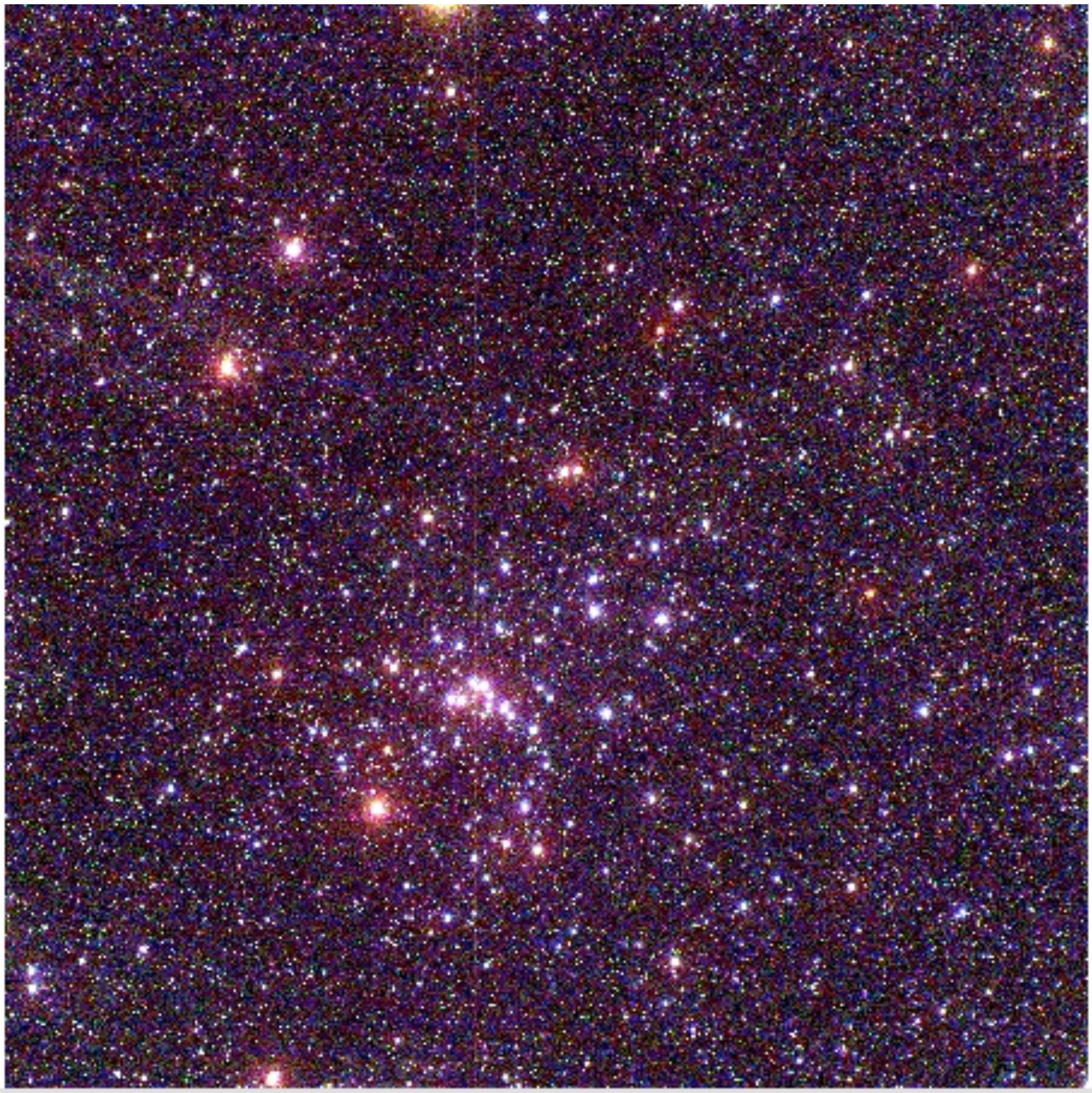

Figure 3: The open star cluster M48 on the University of Michigan Department of Astronomy's Curtis-Schmidt telescope and Tek2k#5 camera. With the Tek2k#5 camera, the field-of-view is 1.3 deg (at 2.3 arcsec/pixel). This color image was constructed from 30 second exposures in SDSS *g*, *r*, *i*, taken on the night of 6 March 2000. Analysis by Rider et al. (2004) of these data (in cross-comparison with data taken with the USNO-1m telescope at Flagstaff Station, Arizona and with the SDSS Photometric Telescope) indicates that the Curtis-Schmidt telescope is easily capable of achieving 2% photometry. (Photo Credit: J. Allyn Smith)